

TIME COMPARISON VIA OTS-2

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ABSTRACT

Since 1980 time comparisons are carried out via OTS-2 between the Technical University Graz (Austria) and the Van Swinden Laboratory Delft (Netherlands).

The method has been based on the use of the synchronization pulse in the TV-frame of the daily evening broadcasting of a French TV-programme to Northern Africa.

Corrections, as consequence of changes in the position of the satellite coordinates are applied weekly after reception of satellite coordinates from ESOC.

A description of the method is given as well as some of the particular techniques used in both the participating laboratories.

Preliminary results are presented.

Starting January 1982 the experiment will be supported by the EEC and enlarged by participation of NPL, PTB, DFVLR, LPTF and IEN.

INTRODUCTION

In order to improve (inter-)national time comparisons over long distances, as much as possible independent of atmospheric disturbances and other obstacles between the participating institutes, the application of several types of satellites and pulse transmission systems is investigated.

Although several satellite systems have proven to give possibilities for excellent time comparisons, so far most of the systems are limited from the point of view of continuous availability, continuous accessibility, on-site installation possibility, high costs and so on.

Therefore, an investigation is carried out after the application of always available, on-site receivable, easy accessible, low cost satellite systems.

The experiment described here, makes use of the OTS-2 satellite. The first stage is based on the application of a one-way method by making use of the TV-synchronisation method. In this case corrections must be applied for the changes in the position of OTS-2

In a later stage a partly two-way method will be considered.

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MEASURING PRINCIPLE

The time comparison is based on the measurement of the time of arrival of the same agreed event in the signal from a geostationary communications satellite at both sites A and B (figure 1).

The signal used is a TV-broadcast from a groundstation, which is relayed by the transponders on board of the satellite. At sites A and B receiving only stations have been installed. Therefore, the method is a one-way method.

The time difference of the clocks at A and B can be expressed as :

$$\begin{aligned}\Delta t &= [T_A - (t_A' + t_A'')] - [T_B - (t_B' + t_B'')] \text{ or} \\ \Delta t &= [T_A - \frac{(R_A + t_A'')}{c}] - [T_B - \frac{(R_B + t_B'')}{c}] \text{ or} \\ \Delta t &= (T_A - T_B) - \frac{(R_A - R_B)}{c} - (t_A'' - t_B'') \text{ where,}\end{aligned}$$

T_A and T_B are the times of arrival of the same reference

pulse as determined on the time scales in A and B respectively;

t_A' and t_B' are the propagation times from the satellite to A and B respectively;

t_A'' and t_B'' are the delay times of the signal in the stations

A and B respectively;

R_A and R_B are the ranges from the satellite to A and B

respectively;

c is the speed of light.

t_A'' and t_B'' are constant and can be determined

t_A' and t_B' are depending of satellite movements of the geostationary satellite.

In order to achieve high accuracy, the geographic position of the receiving stations and the position of the satellite must therefore be known with high accuracy.

Due to the relative small baseline from A to B and the large ranges R_A and R_B to the satellite a geometric configuration

exists in which the first order influences of the satellite movements are cancelled.

OTS-2 SATELLITE

The satellite used is the Orbital Test Satellite (OTS-2), launched by the European Space Agency, on May 11, 1978 and positioned at 10 °E in the geostationary orbit. The expected lifetime of the satellite extends to 1983.

In the communications field several experiments are carried out with OTS-2.

Some details of the satellite and its payload are give in the figures 2 through 5.

The time comparison experiments are done by making use of a TV-signal sent from France to Northern Africa during the evening hours.

The received carrier frequency is 11.682 GHz. The TV-signal is FM-modulated and occupies a bandwidth of 36 MHz. The signal uses energy dispersal following CCIR-recommendations.

OTS-2 ORBIT DETERMINATION

The satellite position is calculated by the European Space Operations Centre (ESOC) in Darmstadt (FRG).

The ranging data are determined by the ground stations Fucino (Italy) and--partially-- Villafranca (Spain).

From these data ESOC calculates the OTS-2 orbit, which gives an accuracy of about 2,6 km (1 σ) for the position, when manoeuvres are absent. This orbit determination is carried out every week over a period which lasts from Wednesday to Wednesday.

Taking into account the geometry of the position of TUG, VSL and OTS-2 the next table shows the consequences of position uncertainty of OTS-2 on the accuracy of the time comparison.

position uncertainty	east-west	north-south	height
	2.5 km	2.5 km	2.5 km
resulting time error	175 ns	65 ns	8 ns

Table 1 : Time errors resulting from the uncertainty of the spacecraft position

RECEIVING STATIONS

TUG, GRAZ, AUSTRIA

The timekeeping station of the Department of Communications and Wave Propagation (INW) of the TUG is located at the Observatory Lustbühel, Graz.

The satellite receiving station, which is also managed by the INW is used for various propagation experiments and is therefore rather complex.

In figure 6 a simplified block diagram shows the configuration for the time comparison.

In table 2 some of the relevant station characteristics are given.

The antenna together with the antenna box is computer controlled in azimuth and elevation. The dish can be heated and the antenna box with the RF-equipment is fully airconditioned.

The received signal is converted down to 70 MHz and fed into an industrial type TV-receiver with a bandwidth of 36 MHz and provided with a threshold extension video demodulator and a videoclamp, which provides more than 40 dB rejection of the energy dispersal wave form.

The video signal ($1V_{PP} + 3 \text{ dB}$ into 75 ohm) is transmitted by a coaxial cable with a length of 50 m from the antenna building to the time keeping station in the observatory.

The station clocks are HP cesium beam frequency standards.

The laboratory is further equipped with several Loran-C and LF/VLF receivers.

VSL, DELFT, NETHERLANDS

The time-/frequency standards laboratory is part of the Van Swinden Laboratory of the National Service of Metrology (Ministry of Economic Affairs).

Figure 7 shows a simplified block diagram of the receiver configuration.

The most relevant station characteristics are given in table 2.

The antenna with the antenna box is remote controlled in azimuth and elevation, out from the time-/frequency standards laboratory.

The antenna is placed on top of the laboratory and is connected to the time-/frequency standards laboratory by a coaxial cable with a length of 140 m

The station clocks are HP cesium beam frequency standards. The laboratory is equipped with several Loran-C and LF/VLF receivers.

THE REFERENCE POINT IN THE SIGNAL

The common reference point/event is the trailing edge of the first fieldsynchronization pulse of the video signal. See figure 8.

Special electronic circuitry has been developed in order:

- to reject the DC- offset and energy dispersal waveform;
- to clamp the synchronization pulses to zero volt level;
- to measure and to memorize the positive white peak voltage of the video signal;
- to extract the reference pulse at a fixed percentage of the maximum positive peak voltage of the video signal;
- to provide the positive reference pulse with an amplitude of more than 2 V into 50 ohm;
- to suppress the reference pulse, when the video signal to noise ratio is too bad, e.g. when there is no TV-transmission;
- to provide a positive video-output of half the input signal amplitude into 75 ohm for a video monitor; the digital sound-in-sync pulses are removed, so a stable line synchronization is possible.

The delay in the circuit for the reference pulse is about 10 ns and is very stable; the pulse to pulse jitter being only depending on the video signal to noise ratio.

MEASURING SCHEME, DATA REDUCTION AND COMPUTATION

Since September 2, 1980 the time scales UTC (TUG) and UTC (VSL) are compared by making use of the TV-signals transmitted by the OTS-2 satellite.

Every day, beginning at 18h10min 00s UTC the first measurement is made, followed by one measurement every two seconds. up to a total of 20 measurements (last measurement 18h10min38s). This series of twenty measurements is repeated every hour with the last series ending at 22h10min38s UTC.

Each series of measurements is followed by a Loran-C measurement of the transmitter Sylt (7970W), which is one of the slaves of the Norwegian Sea chain. For the rest, the actual number of measurements per day depends mainly on the presence and duration of the TV-transmission.

The reference pulses have a repetition rate of 50 Hz.

The time difference between the local time at each station and the reference pulse is measured with an accuracy of 1 ns.

The measuring data are exchanged once a week.

The data are processed in the following way. From each series of 20 measurements a mean value is computed by an iterative process omitting all data outside an originally arbitrary limit ($\pm 0.5 \mu s$) from the resulting mean value. Moreover, this mean value is only used for further computation if the number of measurements used to form this mean is greater than 50 % of the available measurements (on an average 91 % of the available measurements are used). The 1σ standard deviations are also computed and their mean value is about 30 ns.

Also the 1σ standard deviations for the readings of each station are evaluated after removing the systematics by a linear regression through the series of data points and result on an average in a figure smaller than 10 ns for the TUG station and 30 ns for the VSL station.

Next, corrections as consequences of the ranging data are applied. This leads to UTC (TUG) minus UTC (VSL).

Only, still a certain offset is present as a result of so far unknown equipment delays.

The determination of these delays has still to be carried out.

To identify the outliers after correcting for the ranging data, a linear best fit of certain length (50 data points, i.e. 50 hourly mean values or approximately 20 days) is applied.

If the data point in question deviates by no more than a given limit ($\pm 0.5 \mu\text{s}$) from the estimate for this point, which is given by the above mentioned linear regression through the last 50 preceeding and used data points, then this point is used and becomes the last point in the next calculated linear best fit.

A further condition is that only such data points are used which are the mean of at least 10 single measurements. For further processing of the data from the hourly mean values daily mean values were calculated and also the 1σ standard deviation for all measurements of one day (the 1σ values are on an average smaller than 35 ns). The measurements were then corrected for a step (1.6×10^{-13}) in the relative frequency difference of the both time scales. This step is evident from the OTS and LORAN-C data. Thereafter a linear best fit was subtracted from the data. The associated LORAN-C values were processed in the same way.

RESULTS

Figure 9 shows a plot of the hourly mean values of the readings (TUG) minus readings (VSL).

A time step of $9 \mu\text{s}$ in the UTC(TUG) scale at MJD 44744 (May 20, 1981) is removed and furthermore the values for UTC(TUG) before MJD 44564 (November 21, 1980) were replaced by the corresponding values of a second clock (HP 5061A with High Performance Tube) which was used later on to generate UTC(TUG). The overall slope of the curve is caused by the frequency difference (about 7×10^{-13}) of the involved time scales UTC(TUG) and UTC(VSL) respectively. The characteristic shape is due to the change of propagation time resulting from the movements of the satellite.

Figure 10 is a plot of all points which meet the specifications in order to be taken into account for the calculation of UTC(TUG) minus UTC(VSL).

Also plotted in figure 10 are the values of portable clock visits by the U.S. Naval Observatory to both stations. Unfortunately however, the clock visits to both the stations were not carried out on the same trip. Therefore, the plotted values are extrapolations using the clock rates to obtain UTC(TUG) minus UTC(VSL) from UTC(USNO) minus UTC(TUG) and UTC(USNO) minus UTC(VSL).

Fig. 11 shows the residuals of the OTS-2 and the LORAN-C data plus arbitrary constants. The third trace of data points in Fig. 11 presents the difference of the OTS-2 and LORAN-C data for mean values of 10 days (a constant is added to the difference so that the first value is equal to zero). Also indicated are the differences between the OTS-2 results (regression line) and that obtained by the portable clock visits of the USNO (100 ns and - 43 ns respectively). No attempt was made to correct for the difference in the delays of the receiving equipments. The accuracy and precision of this result is mainly determined by the knowledge of the position of the spacecraft. Figs. 12 and 13 show a portion of Figs. 9 and 10 on an expanded scale to demonstrate this effect. The data in Fig. 13 are corrected for the frequency difference of the two time scales and clearly show the influence of the uncertainties caused by the ranging data. Fig. 14 is a stability plot (two sample Allan variance $\sigma_y(2, \tau)$) of the UTC(TUG) - UTC(VSL) time scales compared by TV via OTS-2 and LORAN-C. For sampling times longer than 5 days the stability of the OTS-2 TV-link is better than that of the LORAN-C signal. Also plotted in that figure are the $\sigma_y(2, \tau)$ values if one only uses the data period from MJD 44646 to MJD 44665 (see also Fig. 13). These figures give an estimate of what could be gained by time comparisons using the TV-signal transmitted by the OTS-2 satellite if better tracking data would be available.

CONCLUSIONS

- The given results are not corrected for equipment delays, so the data have a certain offset.
Also a direct transportable clock comparison should be carried out in the near future.
- The ranging data could be improved by the application of another best fit method by ESOC.
This was discussed with ESOC and will be carried out by them.
- From one orbit determination period to the next an offset of up to 200 ns can be seen, especially when there was a spacecraft manoeuvre in between the periods of computation (see Fig. 13 : MJD 44645).
- The receiver at the VSL could be improved in order to achieve less scatter in the readings.
This improvement has been carried out recently.

- The Loran-C data seem to have a strong seasonal dependence. The difference between the Loran-C and OTS-2 results reached 700 to 900 ns for a differential path length over land of 600 km.
The 1 σ standard deviation for the period of one year is 107 ns for the OTS-2 data and 270 ns for Loran-C.
- In January 1982 the OTS-2 experiment will be extended by the participation of NPL, PTB, DFVLR, LPTF and IEN.
The experiment will be supported by the EEC.

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table 2

Main characteristics of the receiving stations

	TUG	VSL
geographical position	47°04'02.88" N 15°29'41.80"E 485.52 m above sea level	52°00'01.85" N 4°22'56.18" E 20.16 m
antenna diameter	3 m	3 m
pre-amplifier	uncooled parametric GaAs Fet	
noise temper- ature	190 K	817 K
down conversion	two stage first IF(750 ± 250) MHz second 70 MHz	single stage (135 ± 18) MHz
antenna gain	48 dB at 11 GHz	47.5 dB
system noise temper- ature	370 K	832 K
figure-of-merit	22,3 dB/K	18,3 dB/K
carrier to noise ratio	16,7 dB	12 dB
TV-receiver	double conversion	single conversion
filter bandwidth	36 MHz	40 MHz
time- interval counter	2 ns	1 ns acc.
data storage	magnetic tape	diskette

The geographical coordinates of the antennae at both the stations are determined by Doppler measurements carried out in Western Europe during the last years. The calculations were made by IFAG, Frankfurt a.Main, (FRG).

Overall Characteristics of Communications Payload (Beginning of Life) Tabel 3

Repeater Chains	A				B	
	Module designation	2	4	4	RL	LR
Repeater Chains	Chain designation					
	Centre frequency					
	- Receive	14172.5	14302.5	14302.5	14457.5	14457.5
	- Transmit	11510.0	11640.0	11640.0	11795.0	11795.0
	Nominal channel bandwidth	40	120	120	5	5
	Overall noise figure	5.0	5.0	5.0	5.0	5.0
	Max. output level	11.5	12.4	11.8	12.3	11.9
	Input level for max. output					
	- Max. gain setting	-101.5	-101.5	-101.5	-123.0	-125.0
	- Min. gain setting	-87.5	-87.5	-87.5	-93.0	-95.0
Beacons	Antenna beam-Polarisation					
	- Receive	Euro 'A' - X	Euro 'A' - Y	Euro 'A' - Y	Euro 'B' - R	Euro 'B' - L
	- Transmit	Euro 'A' - Y	Euro 'A' - X	Spot - Y	Euro 'B' - L	Euro 'B' - R
	Maximum EIRP at beam centre	38.0	47.9	47.3	41.4	41.0
	Maximum G/T at beam centre	-3.0	-3.0	-3.0	-0.4	-0.4
	Beacon designation					
	Frequency	TM	TM	TM	B ₀	B ₁
	Output level	11575.0	11575.0	11575.0	11786.0	11786.0
		-7.0	-7.0	-7.0	1.6	1.3
	Antenna beam-Polarisation	Euro 'A' - X	Euro 'A' - Y	Euro 'A' - Y	Euro 'B' - R	Euro 'B' - L
	EIRP at beam centre	19.5	19.5	19.5	31.2	31.1

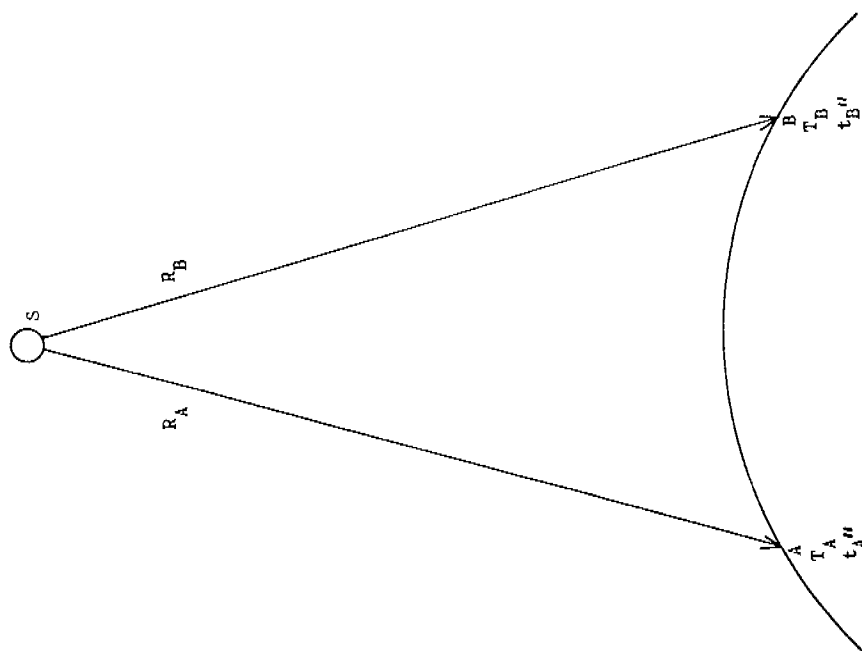


Fig. 1

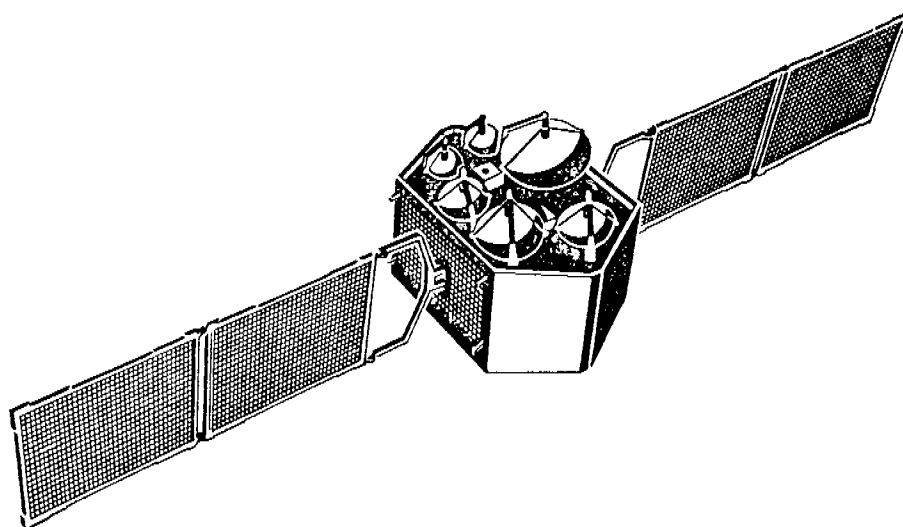


Fig. 2

OTS TRANSPONDER - SYSTEM

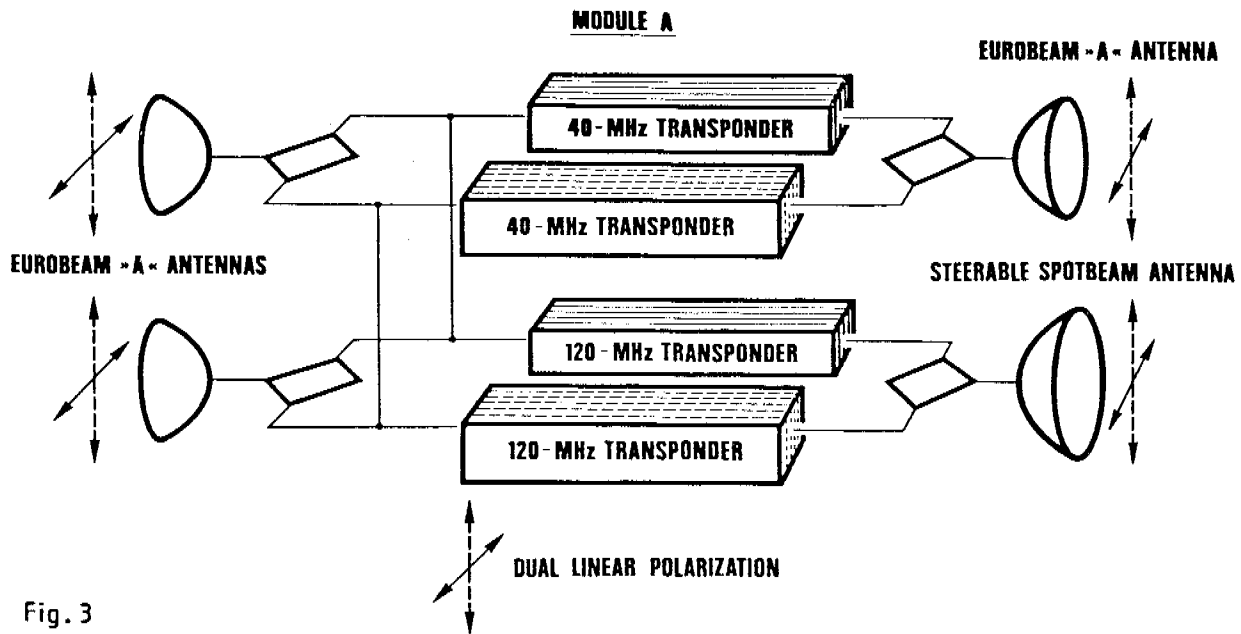


Fig. 3

OTS FREQUENCY PLAN MODULE A

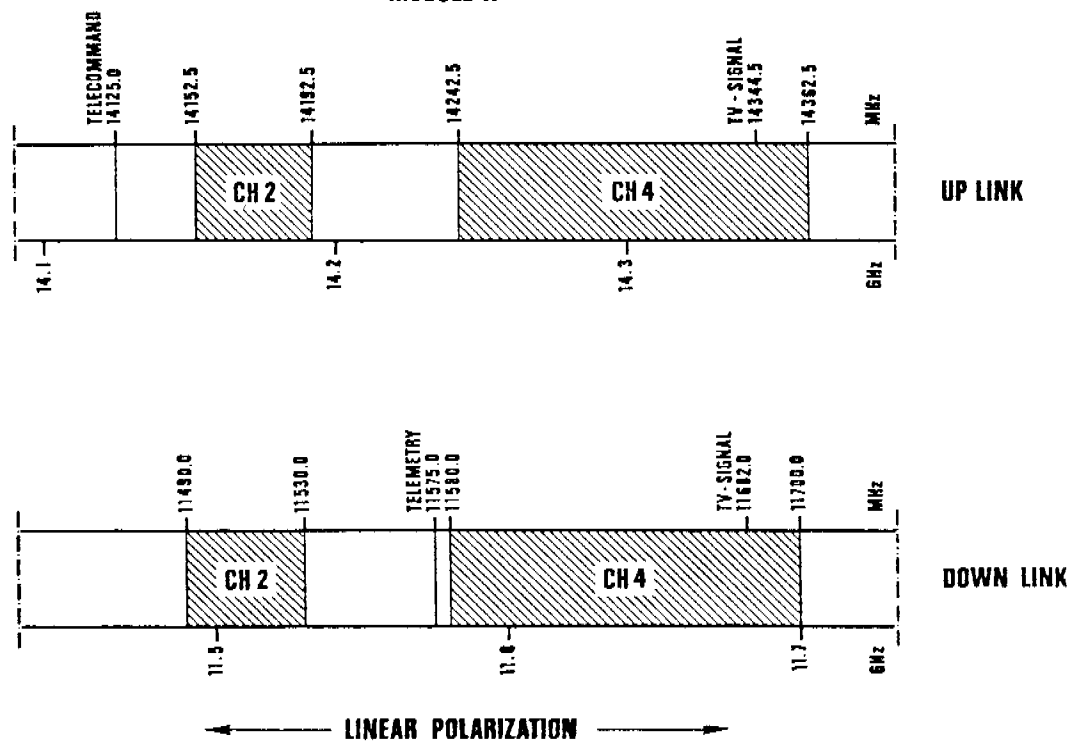
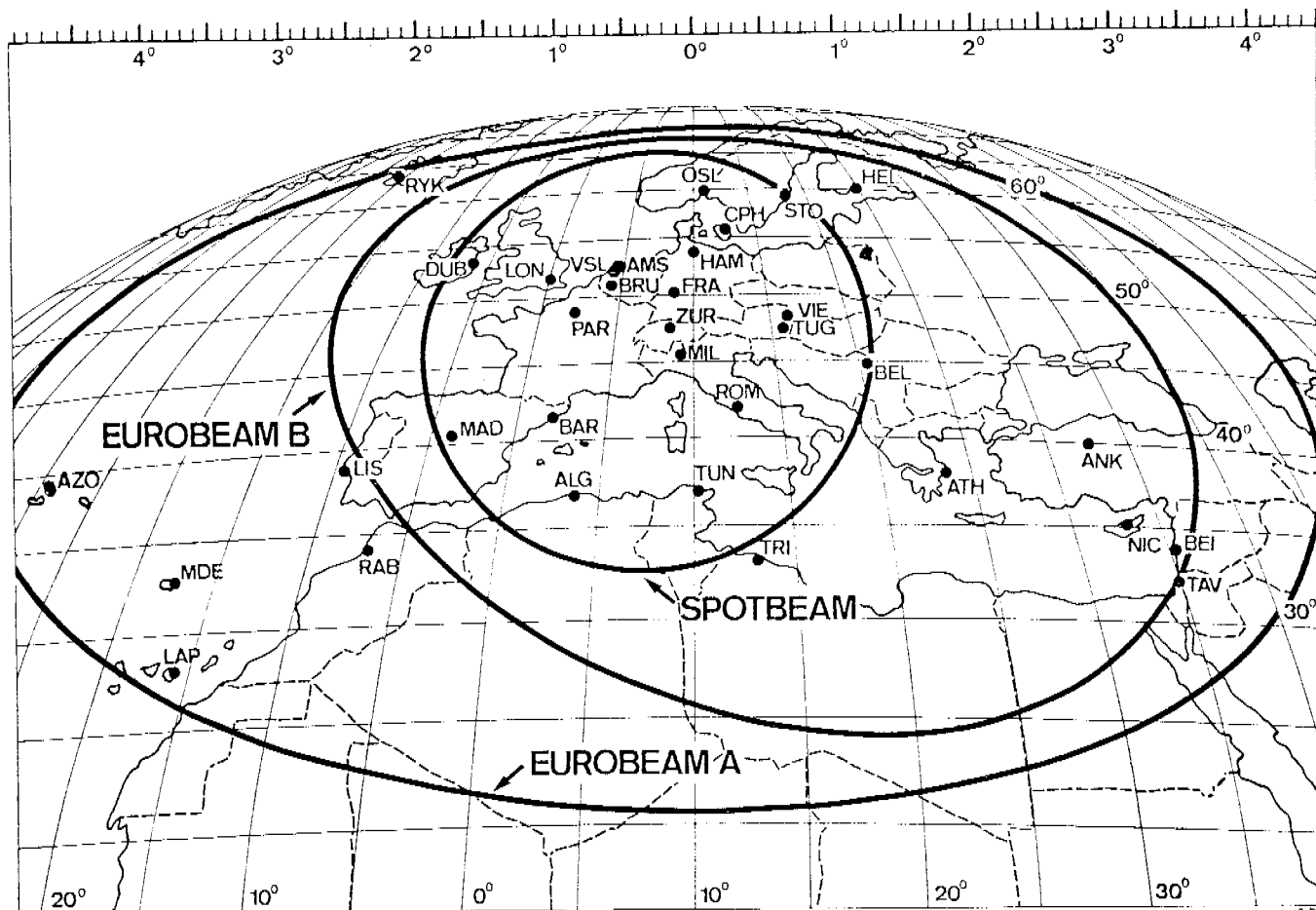


Fig. 4



OTS - COVERAGE ZONES

Fig. 5

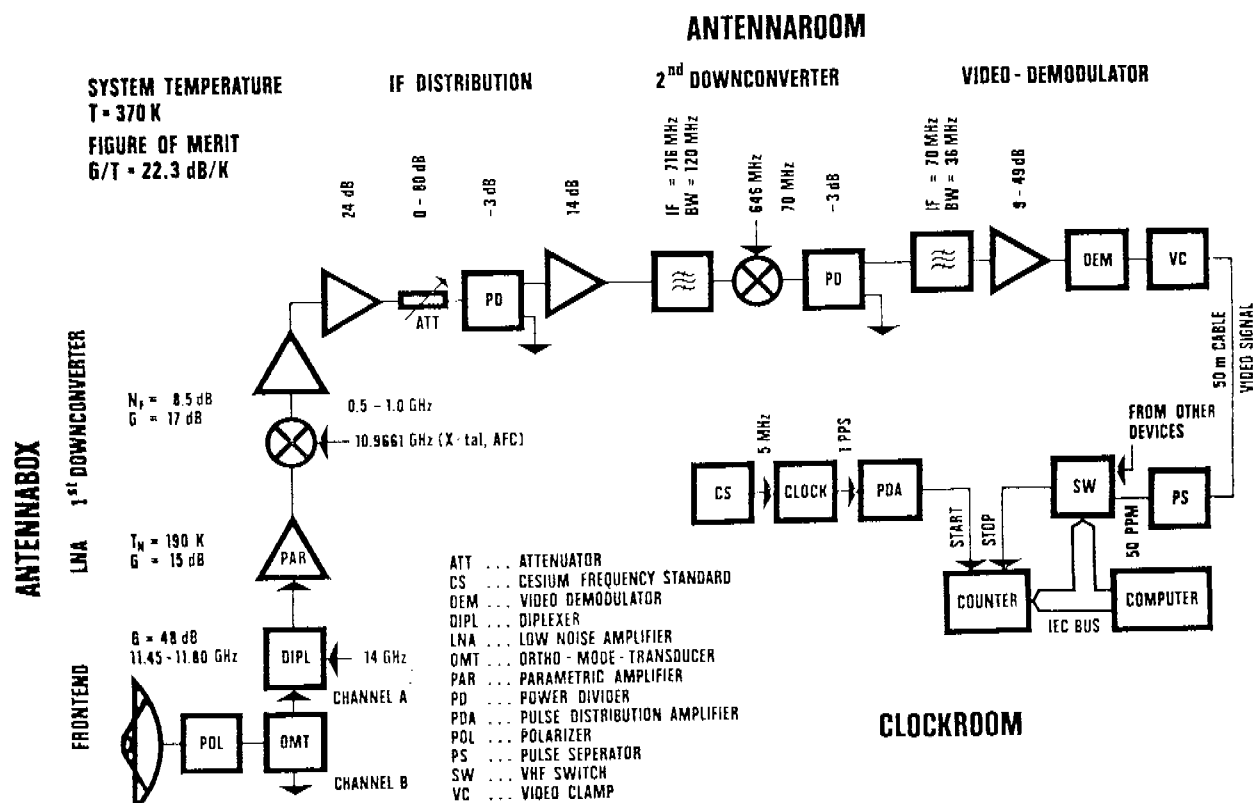


Fig. 6

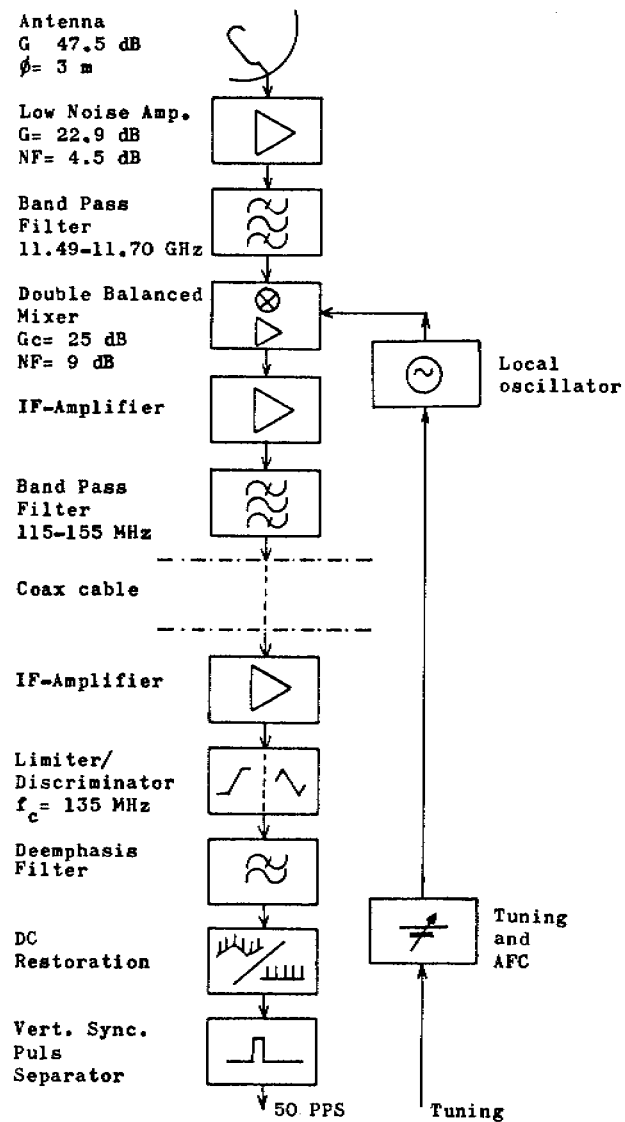


Fig. 7

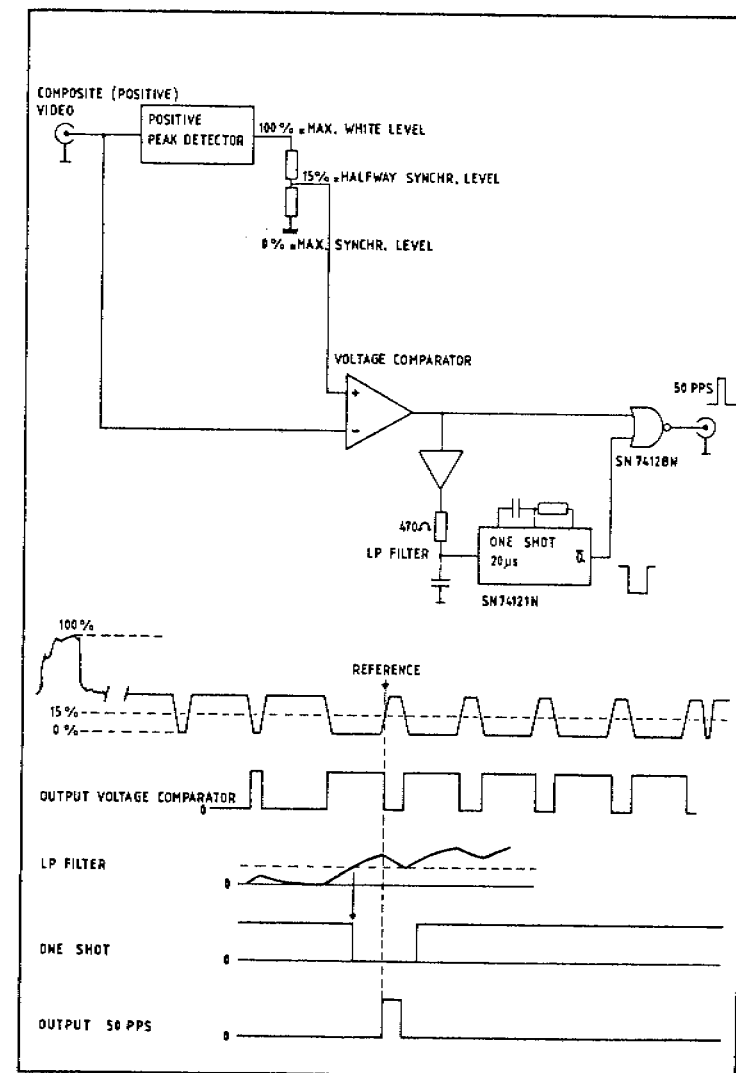


Fig. 8

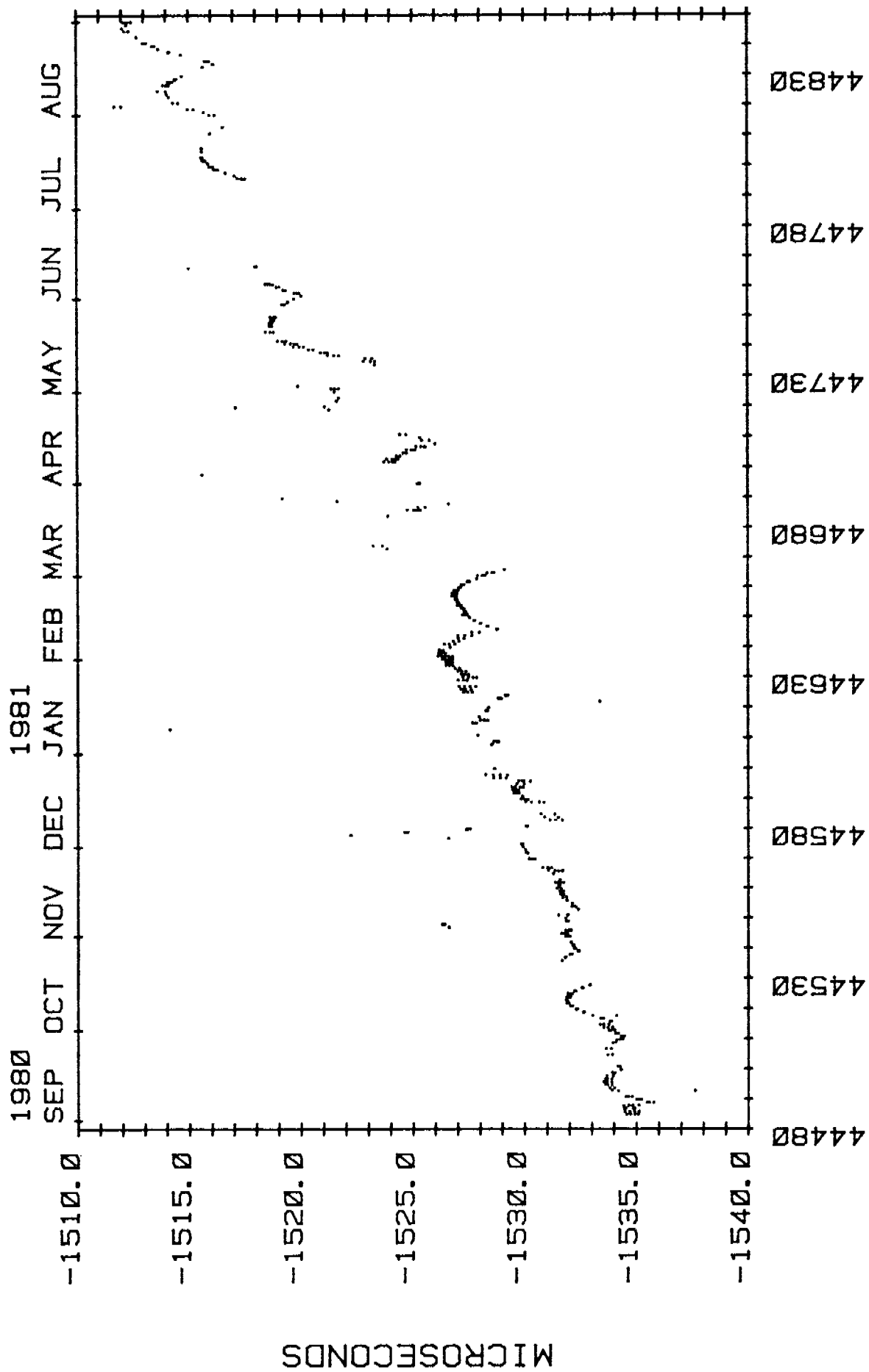


Fig. 9

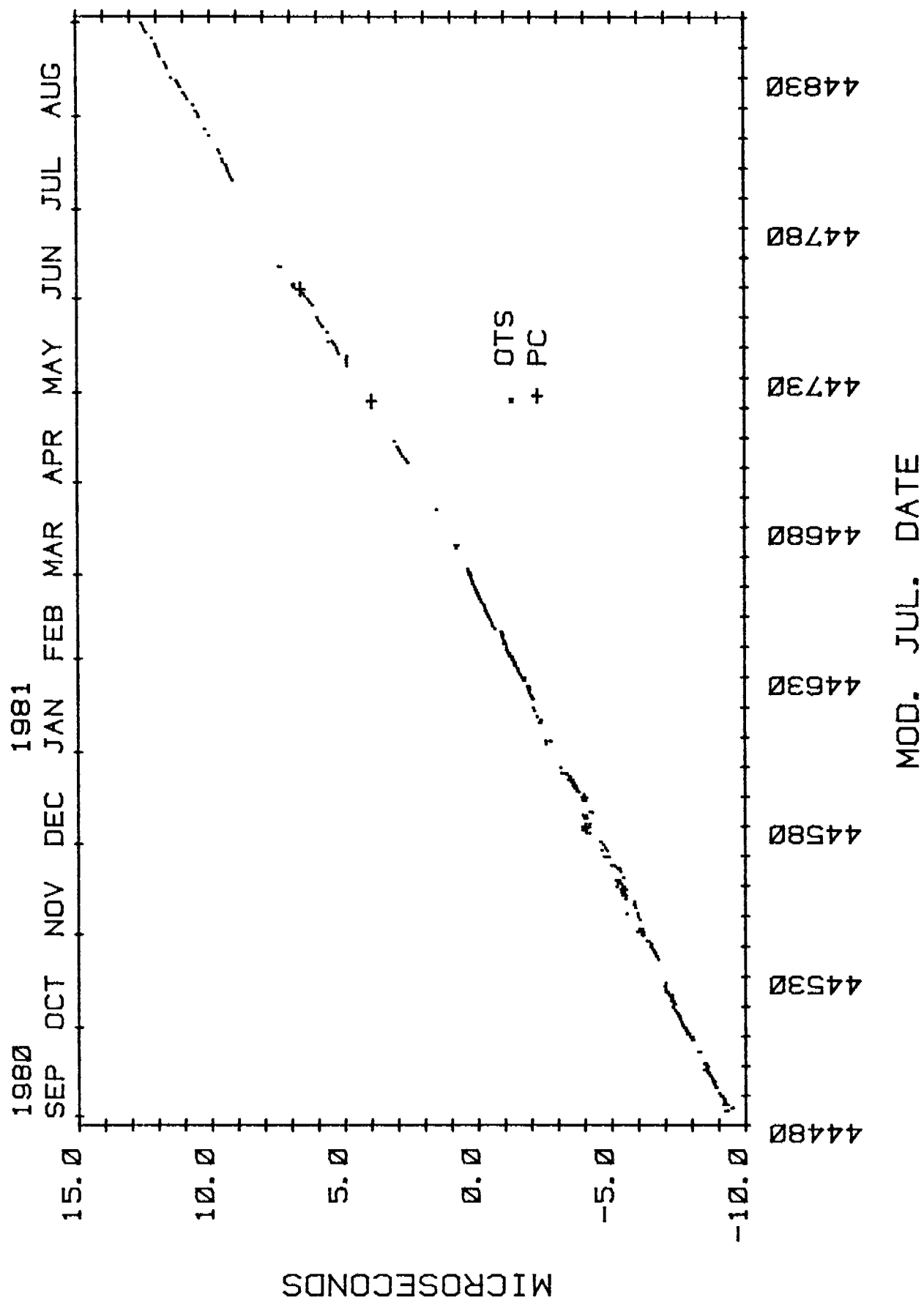


Fig.10

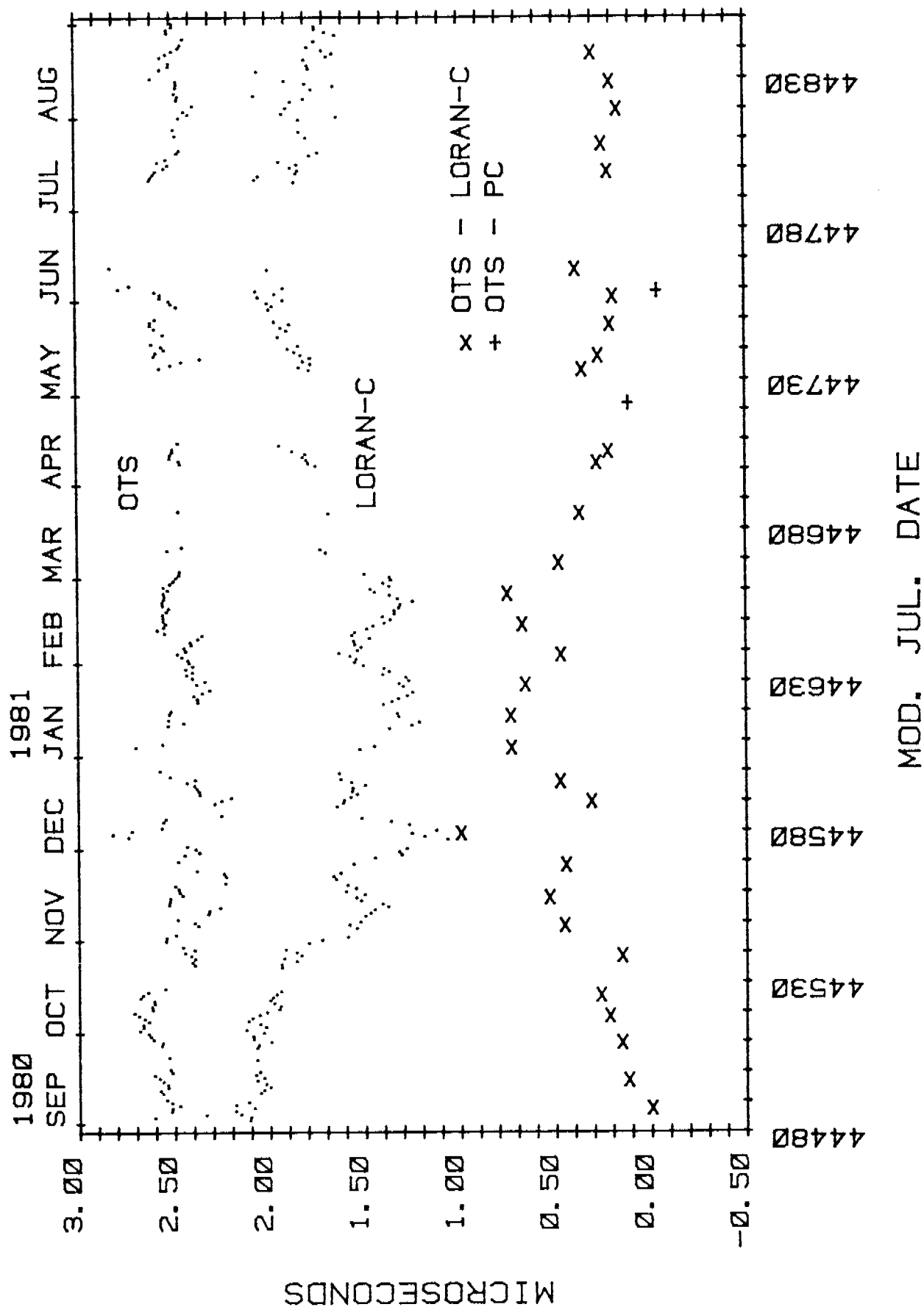


Fig.11

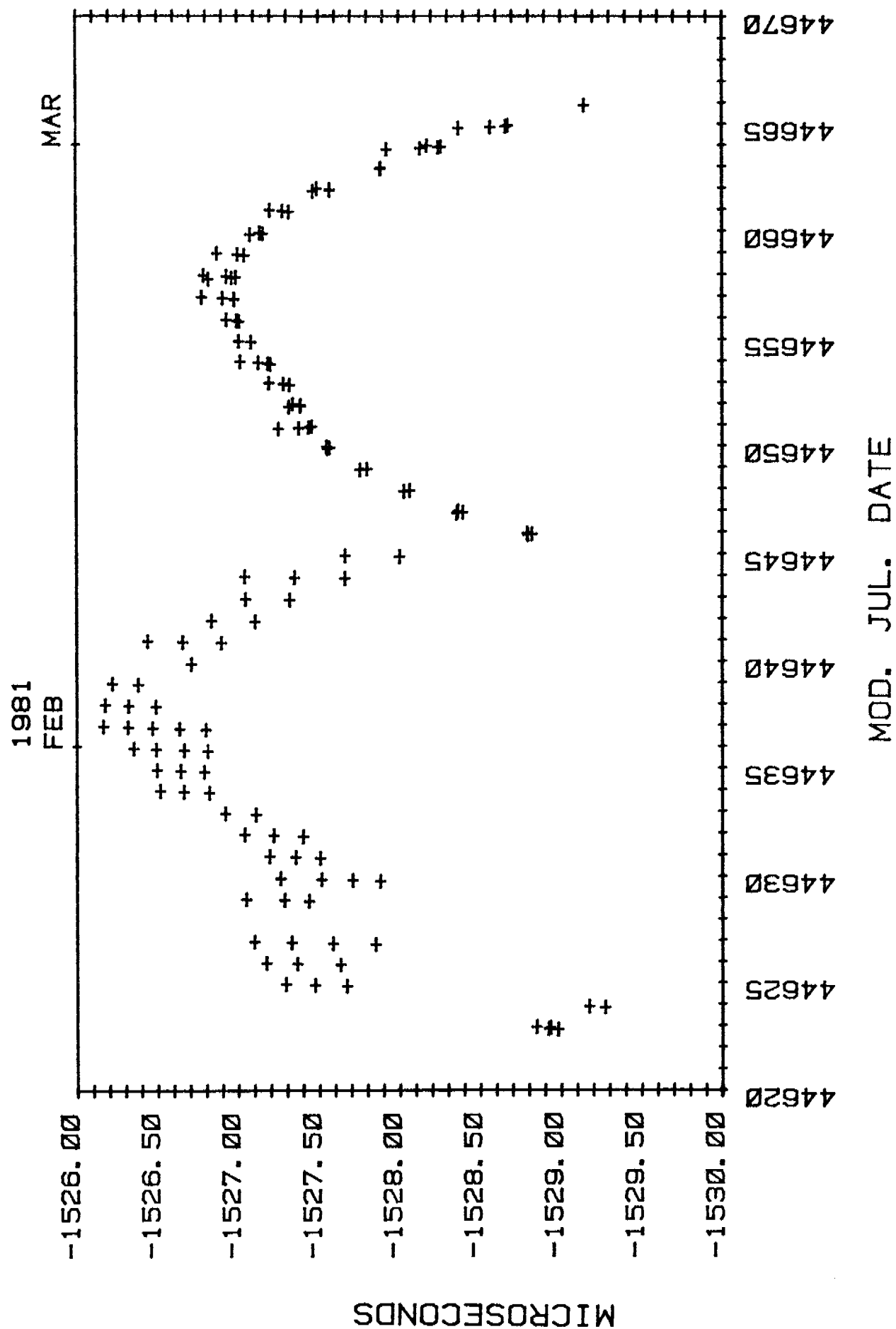


Fig.12

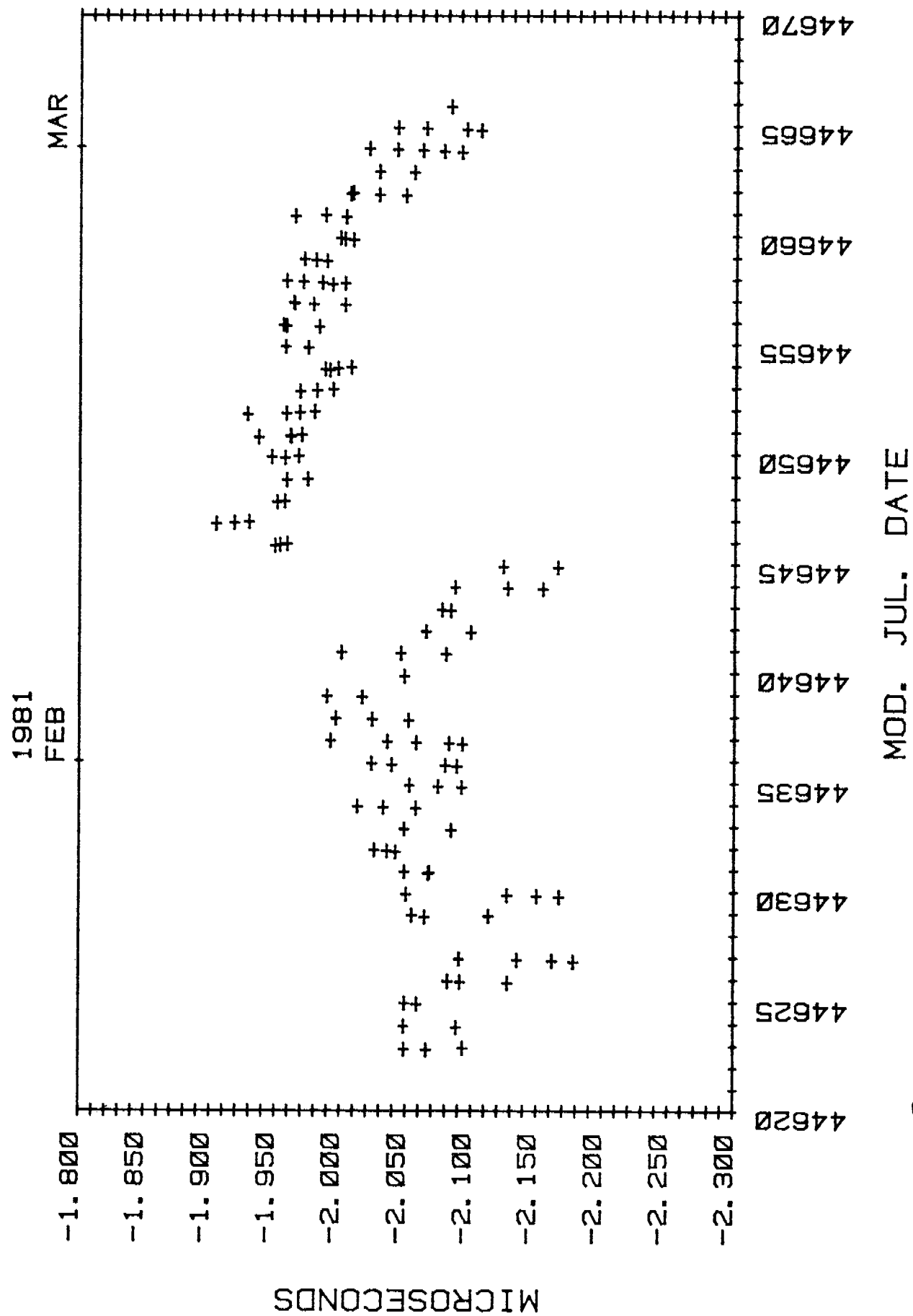


Fig. 13

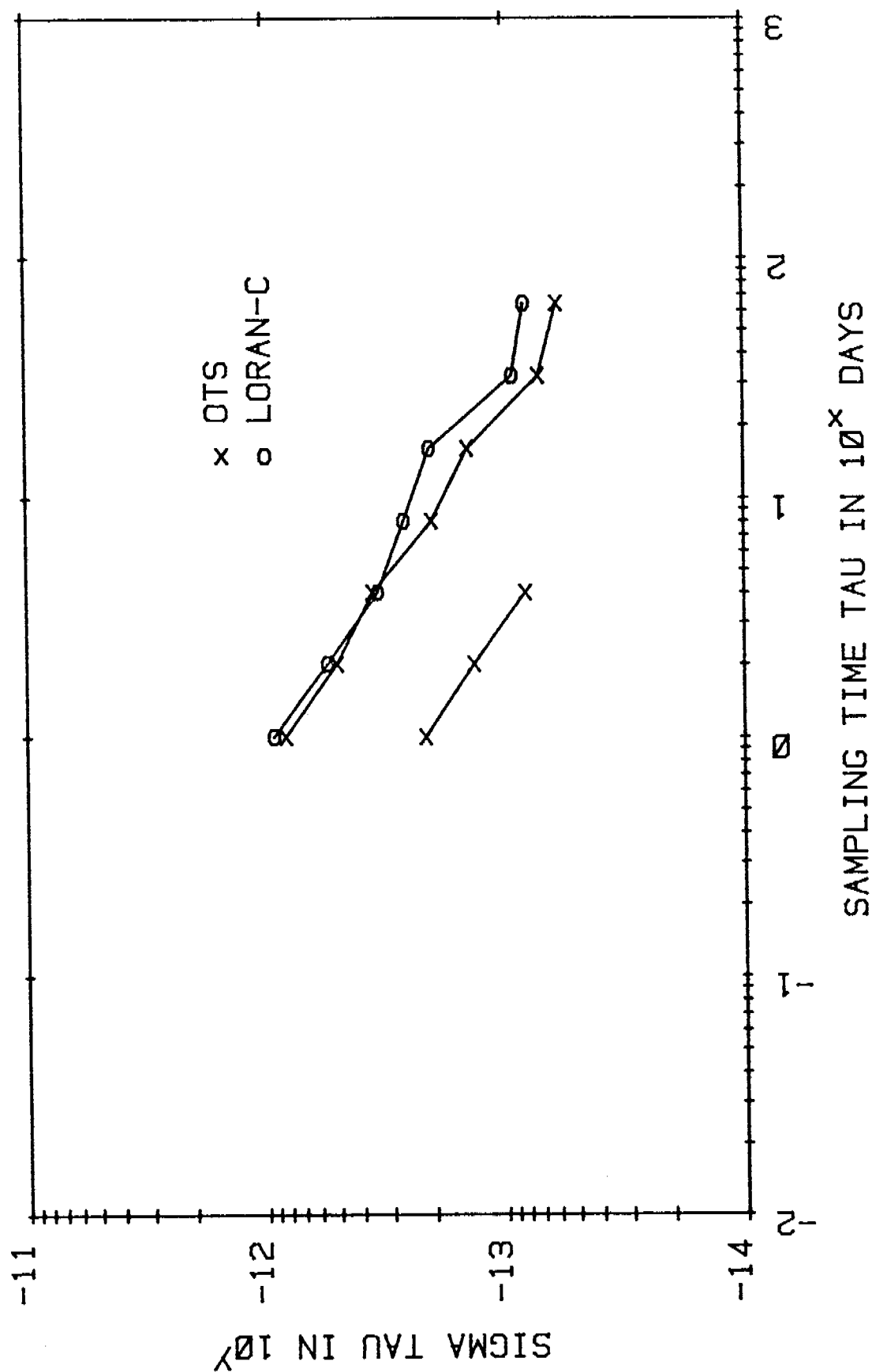


Fig.14

QUESTIONS AND ANSWERS

MR. DAVID ALLAN, The National Bureau of Standards

As you move towards 10 nanosecond level of accuracy, I noticed in your original equations the sagnac was not included, and that between those two sites, it calculates to be about 25 nanoseconds interestingly?

DR. KAARLS:

What was the correction, I'm sorry?

MR. ALLAN:

The sagnac correction.

DR. KAARLS:

Okay. No, it was not included, you are right.

MR. ALLAN:

Yes. And especially as you go to North/South stations where the sagnac will be very small with respect to East/West stations, you will get incontinuity or discontinuities if you don't apply that correction as you get down to the 10 nanosecond region?

DR. KAARLS:

Yes. It might be a factor of importance, yes. Thank you.